



Nanosensors for food safety applications

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science & innovation

Department:
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Outline

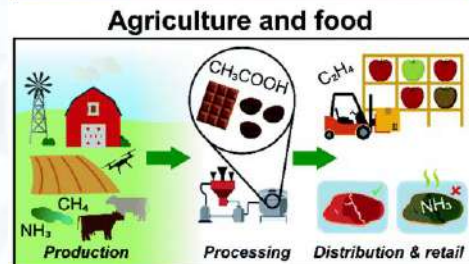


- ❑ Background: Gas sensors
- ❑ Why research on gas sensors?: The need
- ❑ Choice of sensing layer
- ❑ Research interest: Nanosensors for food monitoring
- ❑ Strategic approach
- ❑ Outputs: Ethanol detection
- ❑ Summary
- ❑ Acknowledgements

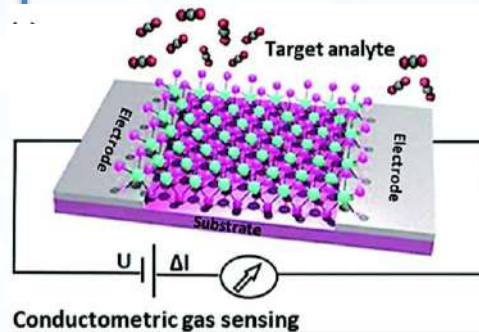
Background: Gas sensors



Gas sensor technology

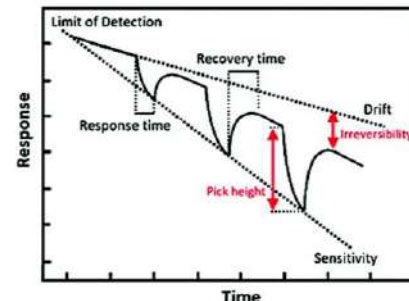


Choice of material



Conductometric gas sensing

Sensor parameters



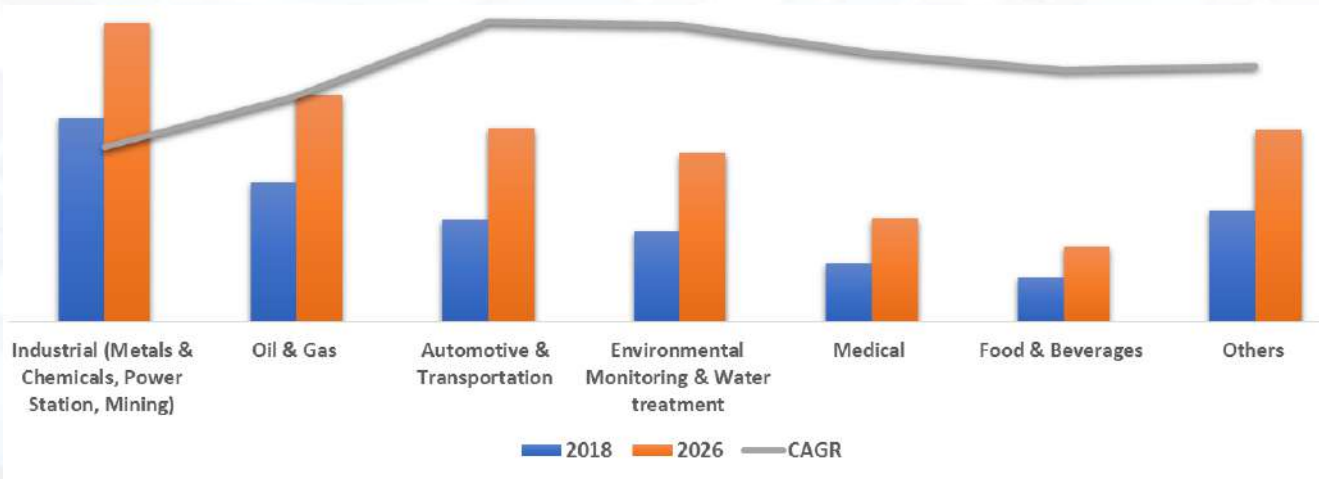
Challenges

1. High operating temperatures (high power consumption)
2. Selectivity – ability to select a specific gas amid others
3. Stability – ability to reproduce the sensing characteristics over a period of time

Approaches to overcome the challenges

1. Morphology engineering
2. Doping/development of heterostructures
3. Surface sensitisation with noble metals

Why research on gas sensors?: The need



[Global Gas Sensors Market Analysis by Top Companies Engineering, AMS AG, Amphenol Corporation AB, MSA Safety Incorporated, Sensirion AG and City Technology \(prweb.com\)](#)

Sensors by technology

- ☐ Solid State/Metal Oxide semiconductor
- ☐ Electrochemical
- ☐ Infrared
- ☐ Optical

Gas Sensors Market Size and Forecast

- ☐ The Global Gas Sensors Market was valued at US \$939.5 million in 2018
- ☐ The Global Gas Sensors Market is projected to reach USD 1,575.9 Million by 2026, growing at a CAGR of 6.81% from 2019 to 2026

Choice of sensing layer



□ T039



□ Morphology engineering



0D to 3D ZnO nanostructures and their luminescence, magnetic and sensing properties: Influence of pH and annealing

K. Shingange^{1,*}, Z.P. Tshabalala², B.P. Dhonge¹, O.M. Nwaeaborwa¹, D.E. Motung¹, G.H. Mhlango^{1,3}

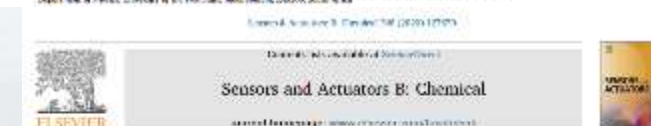
¹Department of Physics, University of Limpopo, Tlokweng Campus, P.O. Box 2015, Sovenga, 0950, South Africa



Tailoring the sensing properties of microwave-assisted grown ZnO nanorods: Effect of irradiation time on luminescence and magnetic behaviour

K. Shingange^{1,*}, G.H. Mhlango^{1,3}, D.E. Motung^{1,3}, O.M. Nwaeaborwa^{1,3}

¹Department of Physics, University of Limpopo, Tlokweng Campus, P.O. Box 2015, Sovenga, 0950, South Africa



Design of porous p-type LaCoO₃ nanofibers with remarkable response and selectivity to ethanol at low operating temperature

K. Shingange^{1,*}, H.C. Swart², G.H. Mhlango^{1,3}

¹Department of Physics, University of Limpopo, Tlokweng Campus, P.O. Box 2015, Sovenga, 0950, South Africa

□ Noble metals loading



A highly responsive NH₃ sensor based on Pd-loaded ZnO nanoparticles prepared via a chemical precipitation approach

G. H. Mhlango^{1,*}, D. E. Motung¹, H. P. Dhonge¹, C. Swart², M. S. Ray³



Highly selective NH₃ gas sensor based on Au loaded ZnO nanostructures prepared using microwave-assisted method

K. Shingange^{1,*}, Z.P. Tshabalala², B.M. Nwaeaborwa¹, B.E. Motung¹, G.H. Mhlango^{1,3}

¹Department of Physics, University of Limpopo, Tlokweng Campus, P.O. Box 2015, Sovenga, 0950, South Africa



Evaluation of the effects of the addition of ZnO on the sensing properties of ZnO nanorods

M. S. Ray^{1,*}, H. P. Dhonge¹, G. H. Mhlango^{1,3}

¹Department of Physics, University of Limpopo, Tlokweng Campus, P.O. Box 2015, Sovenga, 0950, South Africa

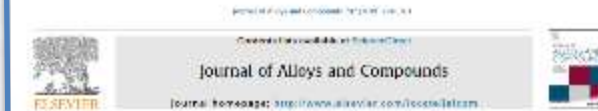
□ Doping and heterostructures



Room temperature ferromagnetism and gas sensing in ZnO nanostructures: Influence of intrinsic defects and Mn, Co, Cu doping

Gaga H. Mhlango^{1,*}, Kankani Shingange¹, Zamiswa T. Tshabalala¹, Babu E. Ehangho², Joyce A. Mahomed³, Bhekani W. Mkhokha⁴, David E. Motung¹

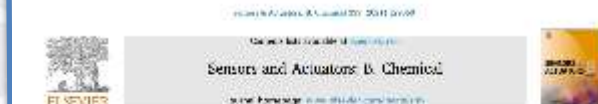
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H₂S detection capabilities with fibrous-like La-doped ZnO nanostructures: A comparative study on the combined effects of La-doping and post-annealing

K. Shingange^{1,*}, H.C. Swart², G.H. Mhlango^{1,3}

¹Department of Physics, University of Limpopo, Tlokweng Campus, P.O. Box 2015, Sovenga, 0950, South Africa



A comprehensive comparison of the effect of magnetic field on the sensing properties of ZnO nanorods and the substitution of ZnO to clarify the origin of enhanced acetone detection capabilities

M.S. Ray^{1,*}, H.C. Swart², G.H. Mhlango^{1,3}

¹Department of Physics, University of Limpopo, Tlokweng Campus, P.O. Box 2015, Sovenga, 0950, South Africa

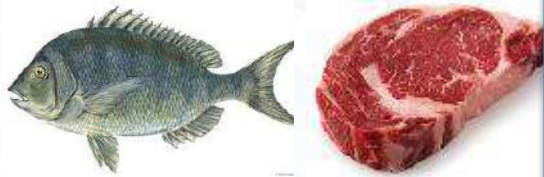
Nanomaterials

- Improved surface area and catalytic activity
- Can further be improved by morphology engineering, doping and noble metals loading

Research interest: nanosensors for food monitoring



Muscle food:



- ☐ NH_3
- ☐ TMA
- ☐ H_2S
- ☐ Ethanol
- ☐ CO_2

Fruit and vegetables:



- ☐ Acetone
- ☐ Ethylene
- ☐ Ethanol

Dairy:



- ☐ Ethanol
- ☐ CO_2
- ☐ Ethylene

Grains:



- ☐ CO_2

Need:

Sensitive, selective and reliable gas nanosensor for food quality status monitoring

Strategic approach



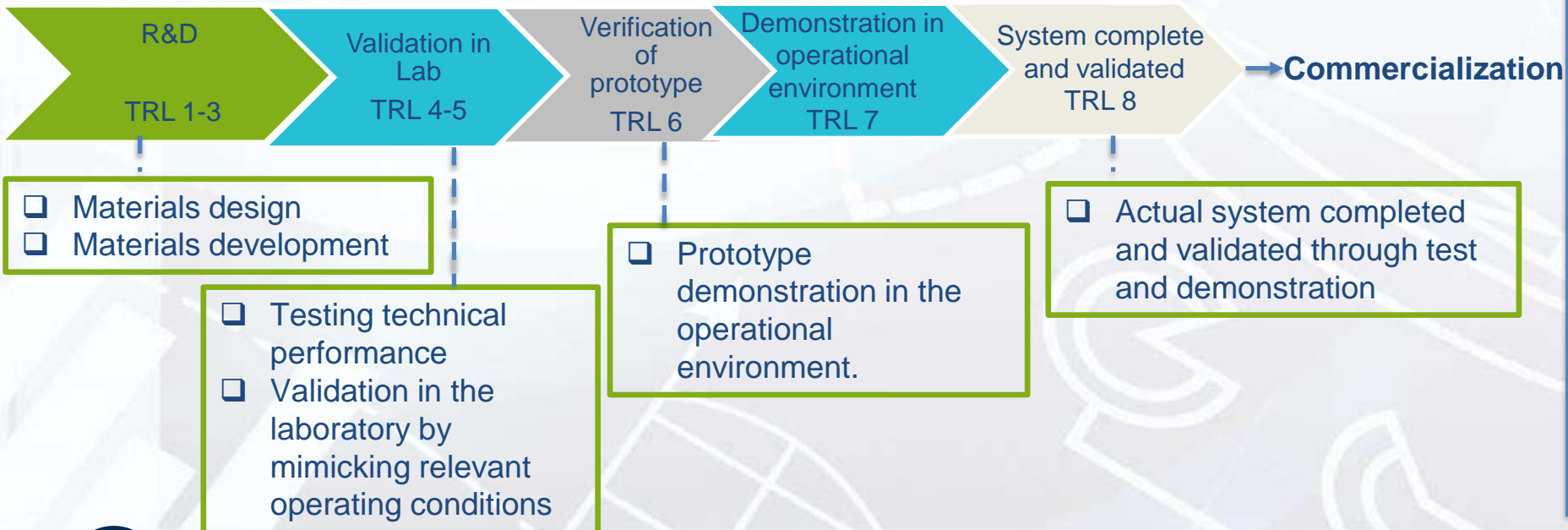
Research goal:

To develop a sensitive, selective and reliable nanosensor for rapid detection of VOCs

- ❑ Integrated full scale pilot systems demonstrated in an operational environment

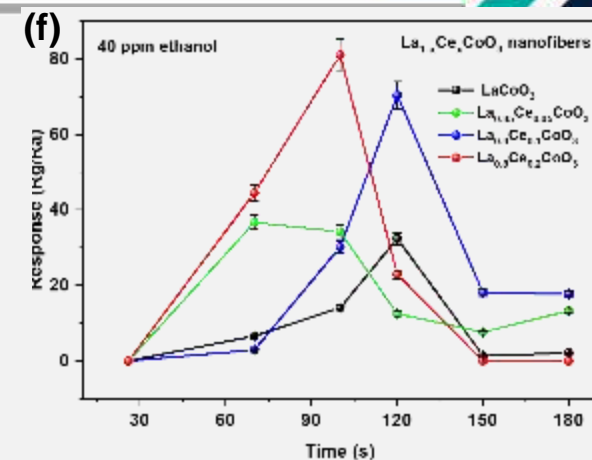
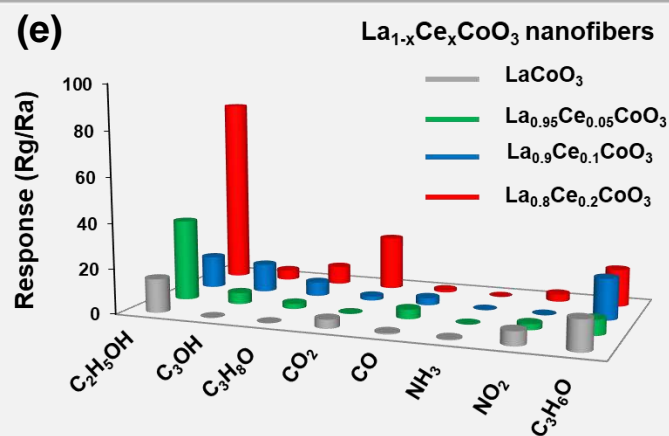
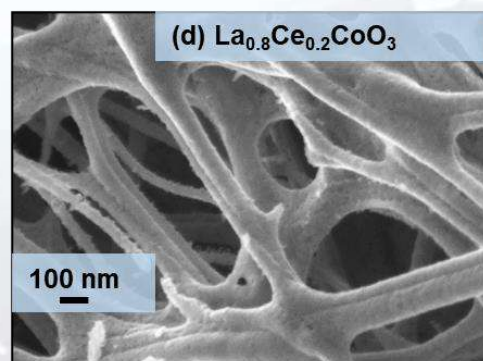
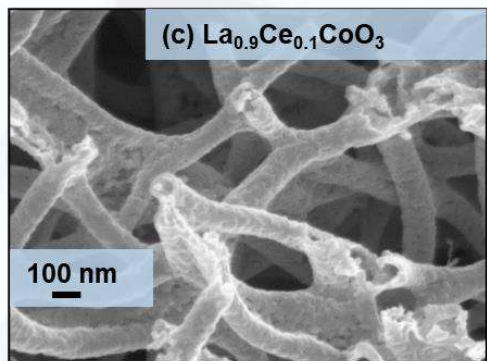
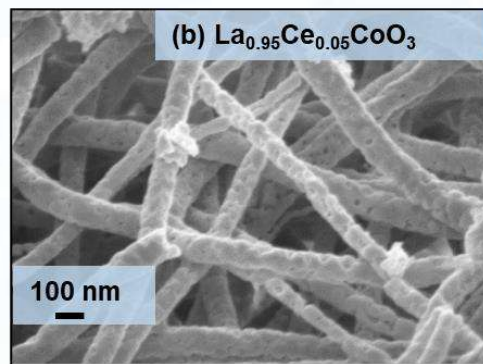
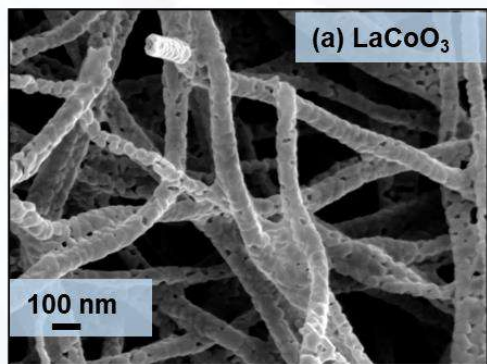
Research objectives:

- ❑ Design nano-enabled based sensors
- ❑ Investigate the nano-enabled based gas sensors performance towards the VOCs emitted by fruit and vegetables as per application specifications
- ❑ Correlate the gas sensing performance to ripening/ spoilage of fruit and vegetables, with focus on ethanol, acetone and ethylene



Outputs: Ethanol detection

□ Motivated by K. Shingange *et al*, Sensor. Actuator: B, 2020



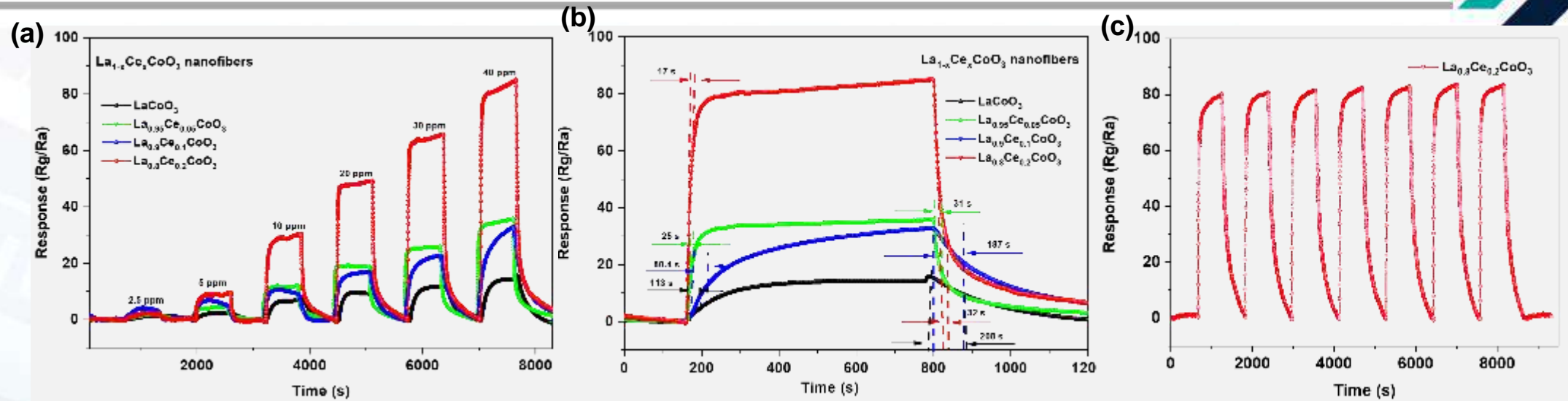
□ Selectivity ✓

□ Temperature dependence ✓

Sensor specifications:

- Range 2.5-40 ppm
- Ethanol selectivity
- Temperature of 100 ° C

Outputs: Ethanol detection continued...

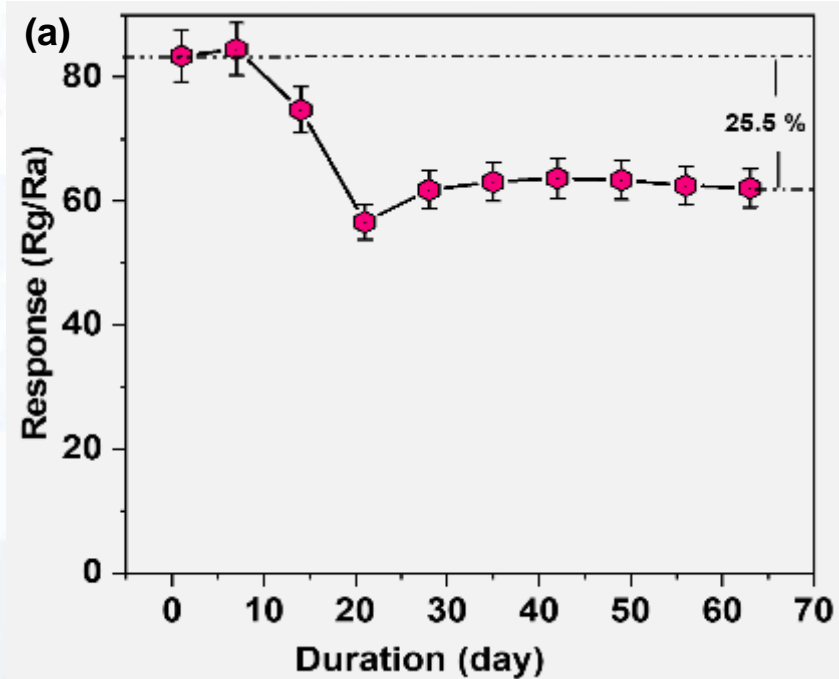


□ Response ✓

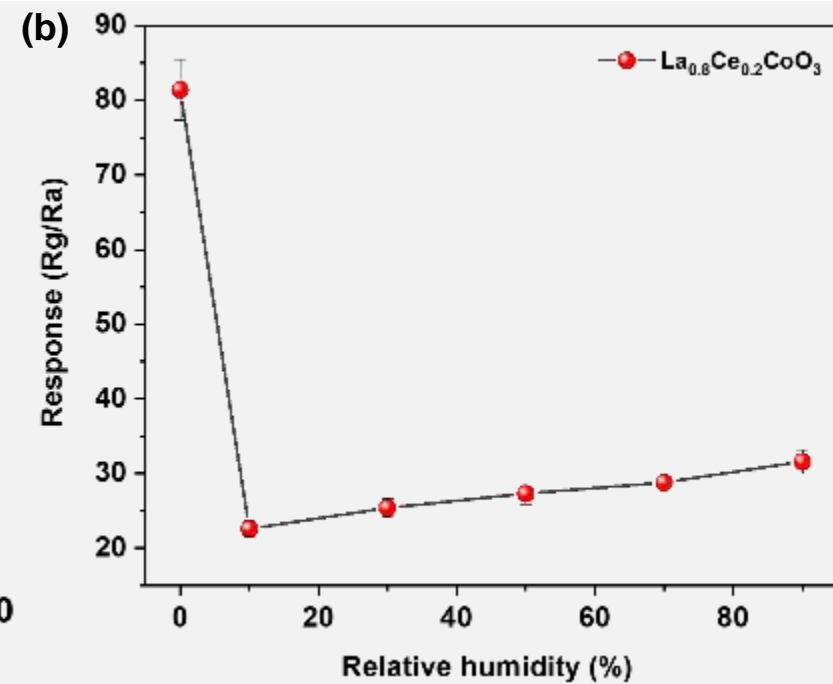
□ Rapid response and recovery ✓

□ Repeatability ✓

Outputs: Ethanol detection continued...



□ Stability ✓



□ Relative humidity ✓

Outputs: Ethanol detection continued...



Sensing material	T (°C)	Conc. (ppm)	Response	T _{res} /T _{rec} (s)	Ref
LaMnO ₃ -SnO ₂	260	100	20	6/34	[1]
Ag/Zn-LaFeO ₃	55	100	64.2	100/20	[2]
La _{0.75} Ba _{0.5} FeO ₃	210	500	136.1	42/40	[3]
LaAlO ₃	350	1000	16.45	16.45/-	[4]
LaCoO ₃	120	40	32.4	26/66	[5]
NiO@LaFeO ₃	240	10	14.7	2/9	[6]
La _{0.8} Ce _{0.2} CoO ₃	100	40	83.4	17/32	This work

[1] D. Chen *et al*, J. Nanopart. Res. 20 (2018) 1-10

[2] M. Chen *et al*, Adv. Mater. Interfaces. 6 (2019) 1801453

[3] J. Xiang *et al*, Mater. Chem. Phys. 213 (2018) 122-129

[4] W. Haron *et al*, Ceram. Int. 43 (2017) 5032-5040.

[5] K. Shingange *et al*, Sens. Actuators B. 308 (2020) 127670.

[6] P. Hao *et al*, Appl. Surf. Sci. 515 (2020) 146025.

Summary



- ❑ The nanofibers demonstrated great selectivity to ethanol along with the sample having the highest amount of Ce ($\text{La}_{0.8}\text{Ce}_{0.2}\text{CoO}_3$) achieving a response greater than twofold the one attained for LaCoO_3 at an operational temperature of 100 °C, as well as rapid response and recovery time of 17 and 32 s.
- ❑ The sensors based on $\text{La}_{1-x}\text{Ce}_x\text{CoO}_3$ nanofibers, particularly $\text{La}_{0.8}\text{Ce}_{0.2}\text{CoO}_3$, could be considered as a prospective energy-efficient material to be utilised for low levels of ethanol molecules detection in applications, such as food shelf-life monitoring in the food industry

Outlook

- ❑ Test at lower concentrations (< 1ppm)
- ❑ Include ethylene for selectivity
- ❑ Stability tests over a longer period (6 months)

Acknowledgements



- ☐ Sensors for food safety group
- ☐ Centre for Nanostructures and Advanced Materials
- ☐ Characterisation facility
- ☐ Council for Scientific and Industrial Research
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THANK YOU